On the Use of Path Diversity with Bursty Channels

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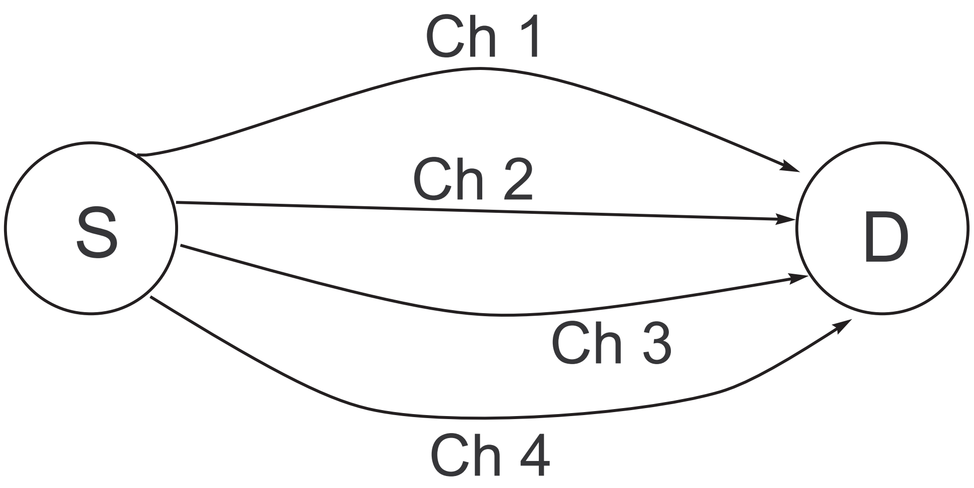
Motivation

- Avoid retransmissions by using some coding.
- Increase the Probability of Success of the transmission.
- Given a minimum desired probability of success, increase the Effective Rate of the system.
- “Robust Networking”

Connectivity Model

- Multiple available paths with different long-term characteristics.
- We consider the case where **two** of the available paths are used.



Setting

- Open-loop environment
  - No real-time (feedback) information on the state of the channels.
  - Only long term statistics are known.
- Applicable in wireless & wired settings
  - More than one channel may be available
  - Long term channel characteristics can be estimated (measured).

Coding

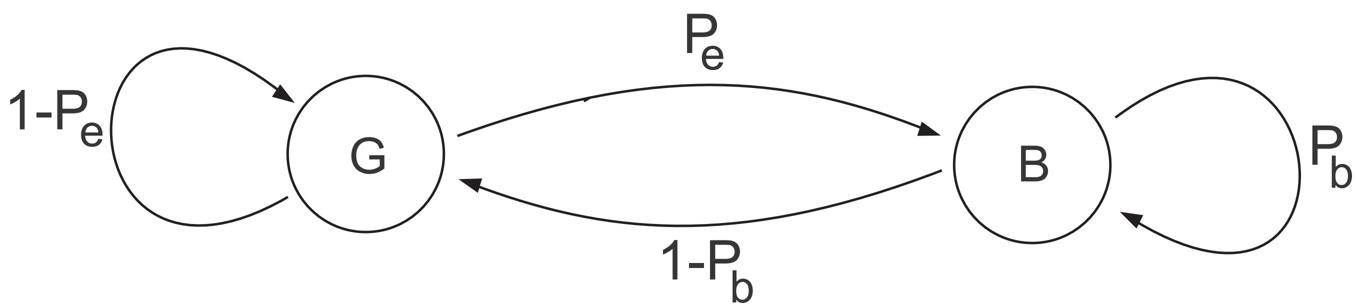
- Use an (N,k) code
  - A block of N symbols can be reconstructed if k or more symbols are received correctly.
  - Introduced under different names in various settings, e.g.,
    - Information Dispersal (Rabin, 1989)
    - Diversity Coding (Ayanoğlu *et al.*, 1990)

Transmission Policy

- How many packets on which channel?
- Focus on simple random policy
- Policy is specified by $p \in [0,1]$
  - Each of the N packets is sent over channel 1 with probability p and over channel 2 with probability $(1-p)$.
- Objective: Maximize performance over all possible policies (values of p).

Channel Model

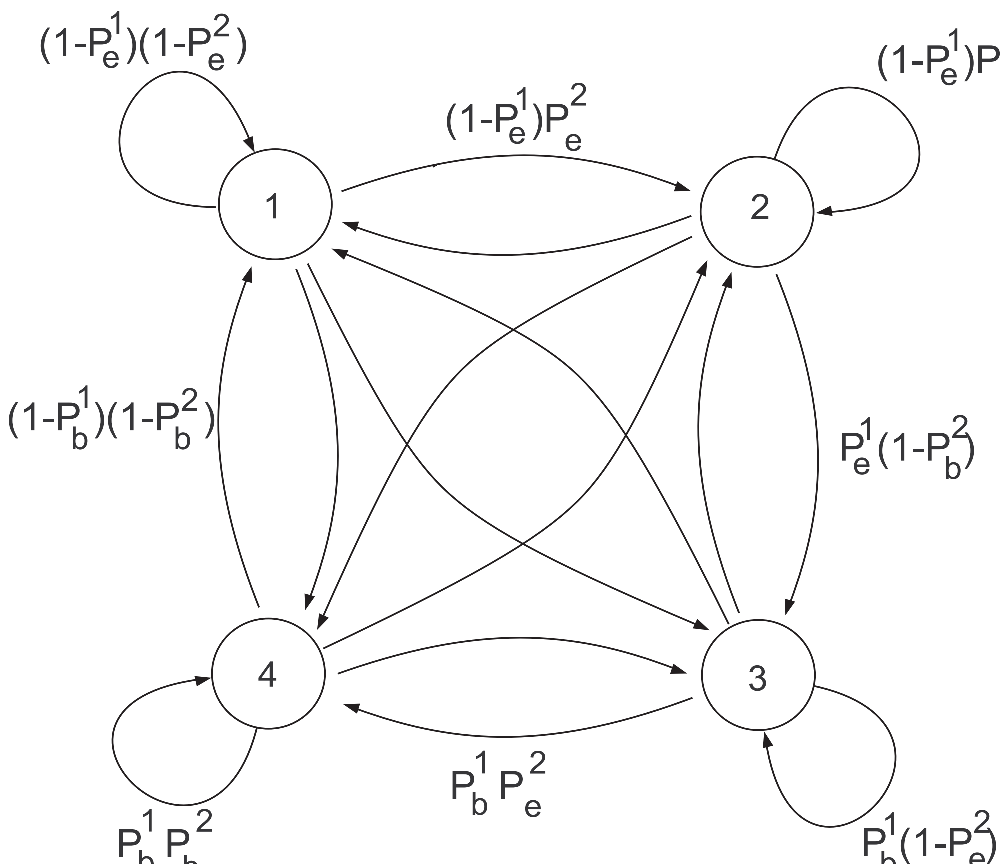
- Use a simplified Gilbert-Elliott model for each individual channel.



- P_e = P{error | previous symbol was correctly received}
- P_b = P{error | previous symbol was in error}

System Model
Two bursty channels

- 4-state Markov Chain



Recursive Expressions

- The probability of success of an (N,k) code can be written as

$$P_{succ}\left(N,k\right)=\sum_{m=0}^{N-k}\sum_{i=1}^{4}\sum_{j=1}^{4}\pi_i P_{ij}\left(m,N\right)$$

where $P_{ij}(m,n)$ corresponds to the probability of exactly m errors in n symbols, starting from state i and ending in state j. It can be recursively calculated via

$$P_{ij}\left(m,n\right)=\sum_{k=1}^{4}P_{ik}\left(m,n-1\right)\cdot P_{kj}\cdot P\{\text{no error}\,|\,\text{state is } j\}$$

$$+\sum_{k=1}^{4}P_{ik}\left(m-1,n-1\right)\cdot P_{kj}\cdot P\{\text{error}\,|\,\text{state is j}\}$$

Performance Metrics

- For a given (N,k) code, by how much can the **probability of success** be increased?
- Assuming a minimum desired probability of success P_{min}, by how much can the **Effective Rate** of the system be increased using the *smallest* possible code?
- By how much can the **Effective Rate** be increased when we use the *best* possible code (given a **maximum allowable code length**)?

Channel Configurations

- We consider two sets of channels
  - Low error rate channels (1-9%)
  - High error rate channels (25-40%)

- The low error rate channels range from random, to bursty (expected length of burst E[B] = 10).
- The high error rate channels range from random, to bursty (expected length of burst E[B] = 20).

Results

Increasing the Probability of Success I

- Consider a (20,12) code and the high long term error rate channels
  - Using both channels can lead to an increase in P_{succ} of up to 70%.
  - The average increase in P_{succ} is about 16.9%.
  - The average P_{succ} using both channels is about 80.2%.

- Average increase in P_{succ} for the (20,18) code is about 387.4%!!
  - The average P_{succ} using both channels is about 28.7%.

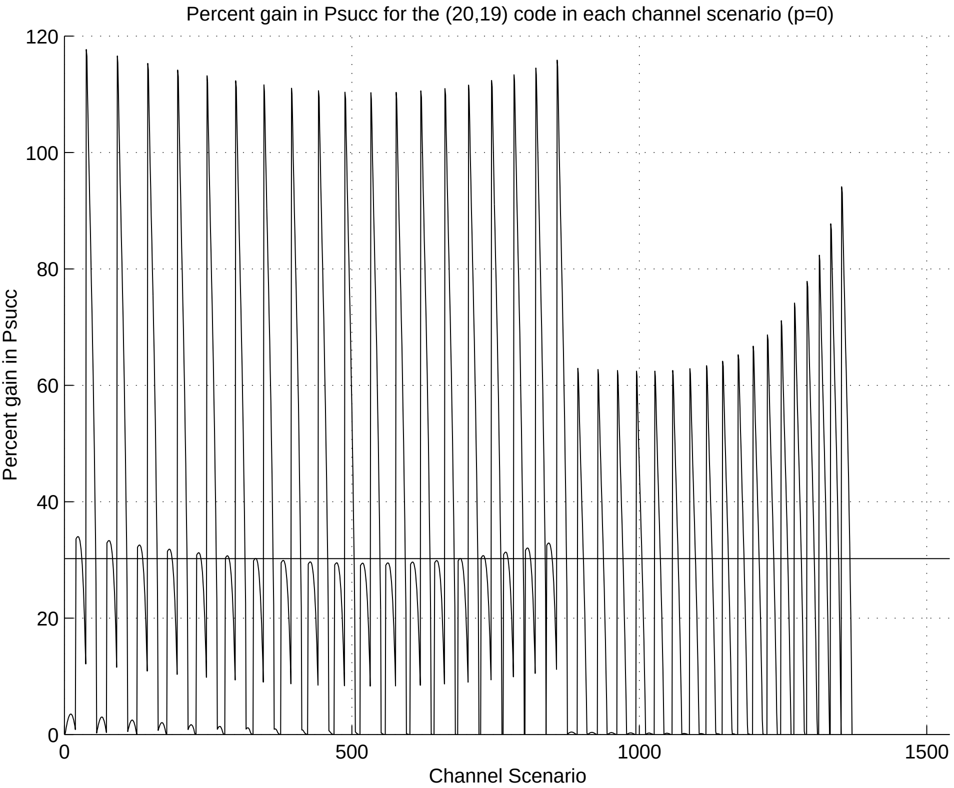
Results

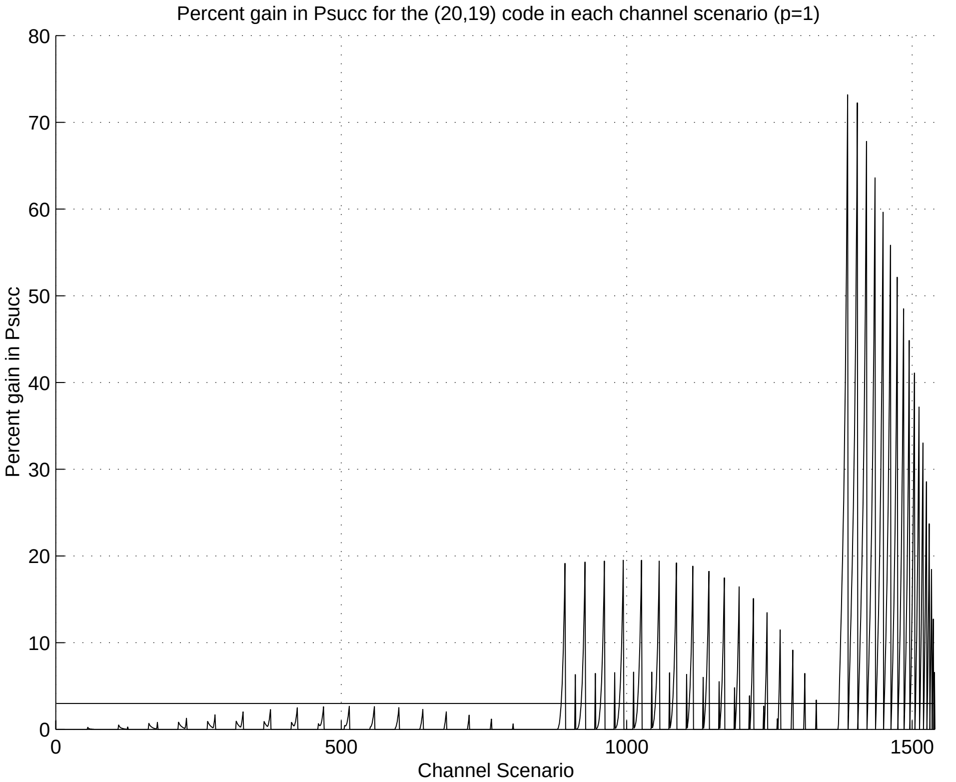
Increasing the Probability of Success II

- Consider a (20,19) code and the low long term error rate channels
  - Using both channels can lead to an increase in P_{succ} of more than 115%.
  - The average increase in P_{succ} is about 17%.
  - The average P_{succ} using both channels is about 86.41%.

Results

Increasing the Probability of Success II





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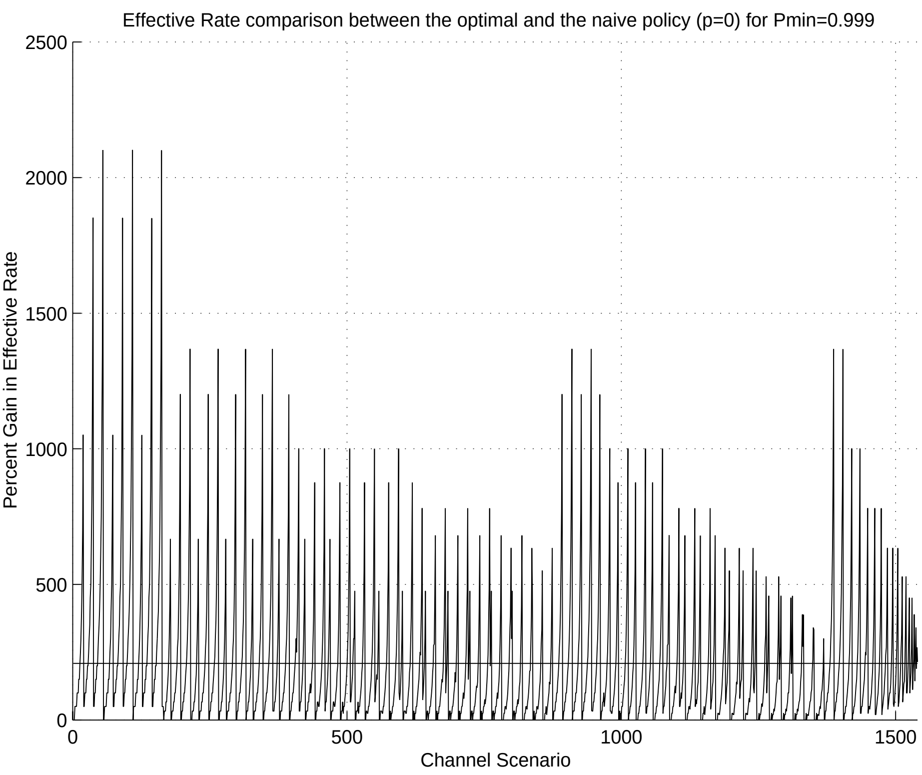
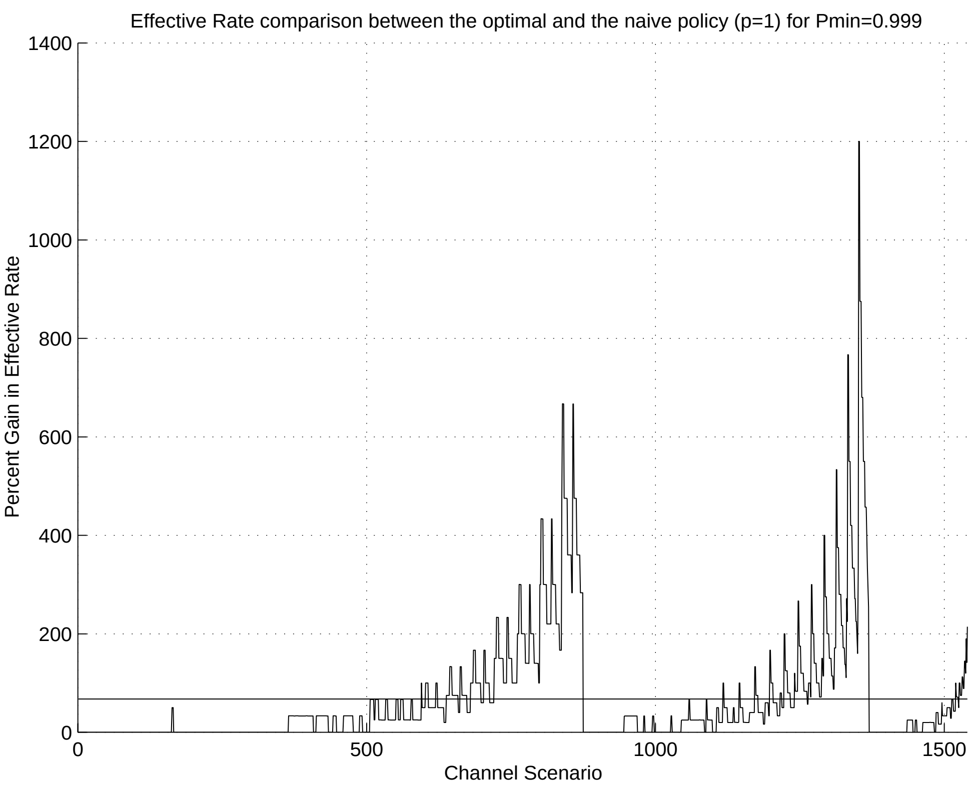
Results

Increasing the Effective Rate

- Consider the low error rate channels.
  - Let the minimum desired probability of success (P_{min}) be 0.999.
  - Use the smallest (N,k) code that achieves P_{min}.
- The increase in Effective Rate can be more than 2000%.
- The average increase in Effective Rate is about 138%.
- Gains are even higher when we consider the high error rate channels.

Results
Increasing the Effective Rate





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Results

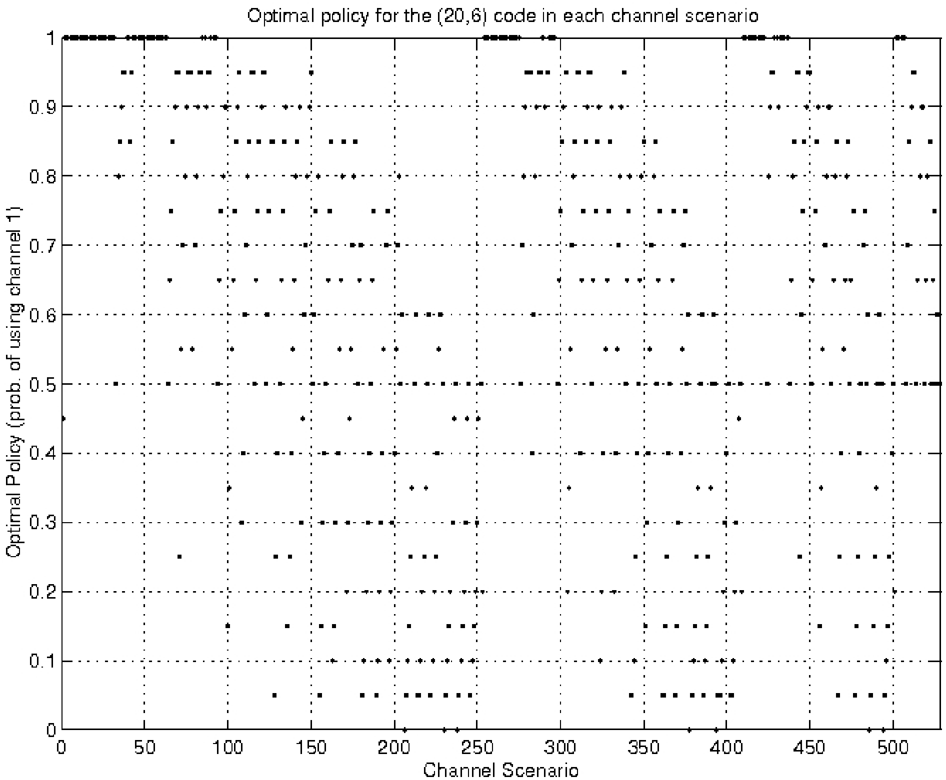
Increasing the Effective Rate for Large Codes

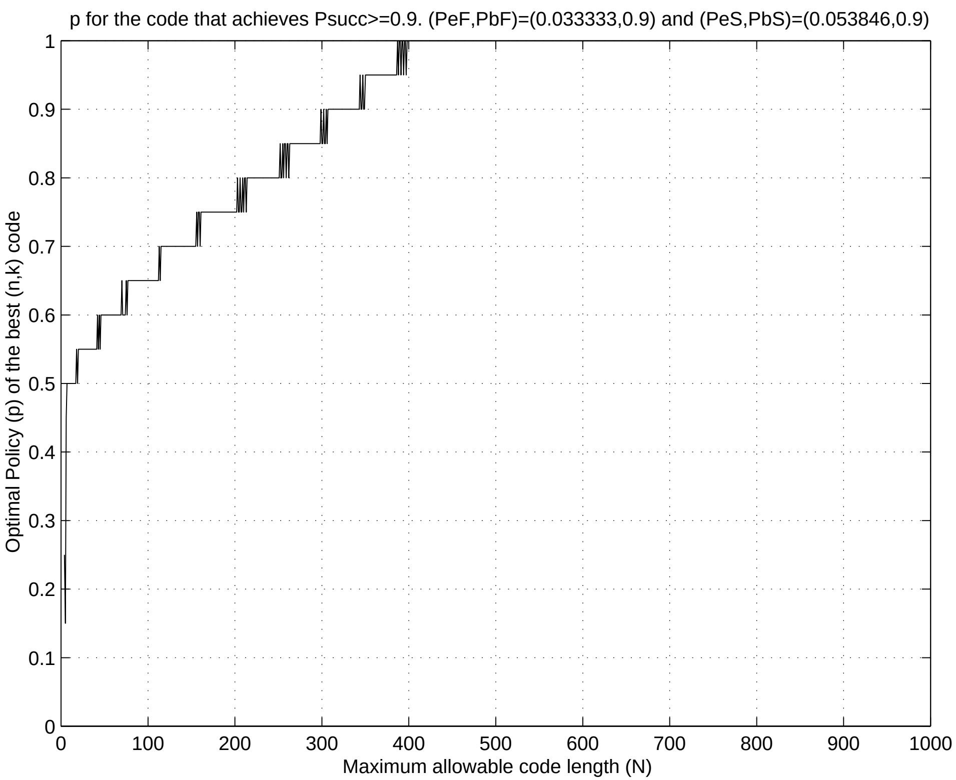
- Consider the case of two identical GSM channels
  - Both channels are bursty (E[B] = 6.67).
  - Long term error rate is 5%.
- When the length of the code is restricted to 50, the gain is about 33%.
- When the length of the code is restricted to 100, the gain is about 17%.
- When the length of the code is restricted to 500, the gain is about 4.2%.

When does it pay to use *both* channels?

- The optimal policy depends on
  - the code length,
  - the relative degrees of "burstiness" of the two channels, and
  - the long term error rates of the channels.
- Identical channels: Optimal policy need **not** be p=0.5.
- When both channels have the same long term error rate (but different expected burst lengths), using both channels can improve performance.
- When one channel has a better long term error rate
  - For a large enough code length, the optimal policy is to always choose the better channel.
  - However, if we restrict the length of the code, it can be still be beneficial to use both channels.

When does it pay to use *both* channels?





Optimal Policy of the (20,6) code for each channel scenario of the high error rate channels.

Optimal Policy as a function of the maximum allowable code length. Both channels are bursty but the second one has a worse long term error rate. High error rate channels.

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Conclusion

- Intelligent use of two channels can improve performance significantly with minimum cost.
  - Only limited channel knowledge is required.
  - Simple (random) transmission policy can be used.
- The optimal transmission policy, i.e., *p*, can be computed efficiently based on
  - the channel characteristics,
  - the code being used (or maximum allowed code length), and
  - the desired target loss probability, P_{min}.

Reference

- Full paper available at http://einstein.seas.upenn.edu/mnlab/publications.html

- E. Vergetis, R. Guerin, S. Sarkar, "Benefiting from Path Diversity with Bursty Losses."